PERFORMANCE REPORT

# A Cockroach-Like Hexapod Robot for Natural Terrain Locomotion

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## Research Progress

• Robot III has been constructed. Based on motion studies of the cockroach, the robot rear, middel and front legs have 3,4 and 5 degrees of freedom respectively. The robot weighs 30 lbs, is 30 inches long (about 17 times larger than Blaberus cockroach) and is constructed of aluminum alloys. The joint degrees of freedom are actuated using double acting pneumatic cylinders. The servovalves are attached at the rear of the robot to place the center of mass at the coxa-body joint of the rear legs, matching the center of mass location of the cockroach. The actuators were chosen to produce approximately 5 times the force necessary for standing. Therefore, the robot should be capable of running and climbing. Potentiometers have been placed at each joint to measure joint angles.

• An accurate dynamic model of Robot III has been constructed and a controller is being developed in simulation. A preliminary postural controller based upon a virtual model technique has been successfully implemented in simulation. The locomotion controller will be implemented as a network of mechanisms and influences at the joint level based upon results from the Ritzmann and Zill labs.

• A motorized treadmill has been constructed to test the robot's locomotion controller. It is large enough (5ft by 6 ft) for the robot to walk and turn and fast enough (4mph) for the robot to run.

• The project describing the relationship between motor activity and joint kinematics for horizontal running on a treadmill has been completed, written up and accepted for publication.

• We extended our observations to the front legs, where joint coordination is markedly different from the middle and hind legs even in horizontal walking.

• A graduate student (Andrew Tryba) is looking at reflex action in front vs. middle and hind legs to determine how differential motor control is accomplished.

• James Watson (postdoc) is moving on to make observations on joint angle and motor activity in animals that are performing more difficult movements.

• Analysis of evolved model central pattern generators (CPGs) has now progressed to a point where we have a good quantitative theory of the best minimal CPG. This theory can predict the consequences of a variety of circuit manipulations, and has proven to be generalizable to a larger population of minimal CPGs. We are currently examining its extension to nonminimal CPGs.

## Publications


Bachmann, R. J., Nelson, G. M., Quinn, R. D., Watson, J., Ritzmann, R. E. (1997). Design of a Cockroach-like Robot. Proceedings of the 11th VPI&SU Symposium on Structural Dynamics and Control, Virginia Tech, May 12-14, 1997.

Bachmann, R.J., G.M. Nelson, R.D. Quinn, J.T. Watson, R.E. Ritzmann, (1997) Development of a Cockroach-like Robot for Climbing and Running. *Soc. Neurosci. Abstr.* **23**: in press.

Beer, R.D., Quinn, R.D., Chiel, H.J., and Ritzmann, R.E. (1997). Biologically-inspired approaches to robotics. *Communications of the ACM* **40**(3):30-38.

Chen, C. T., Quinn, R. D., Ritzmann, R.E. (1997). A Crash Avoidance System Based Upon the Cockroach Escape Response Circuit. Proceedings of the 1997 IEEE International Conference on Robotics and Automation (ICRA '97), Albuquerque, NM, April 22-24, 1997.

Chiel, H.J. and Beer, R.D. (in press). The brain has a body: Adaptive behavior emerges from interactions of nervous system, body and environment. To appear in *Trends in Neurosciences*.

Flannigan, W. C., Nelson, G. M., Quinn, R. D. (1997). Control of a Crab-like Robot with Complex Kinematic Constraints. Proceedings of the 11th VPI&SU Symposium on Structural Dynamics and Control, Virginia Tech, May 12-14, 1997.

Kolacinski, R. M., Quinn, R. D. (1997). Design and Modeling of a Biomimetic Antagonistic Actuator System. Proceedings of the 11th VPI&SU Symposium on Structural Dynamics and Control, Virginia Tech, May 12-14, 1997.

Nelson, G. M., Quinn, R. D., Bachmann, Flannigan, W. C., Ritzmann, R. E., Watson, J. T. (1997). Design and Simulation of a Cockroach-like Hexapod Robot. Proceedings of the 1997 IEEE International Conference on Robotics and Automation (ICRA '97), Albuquerque, NM, April 22-24, 1997.

Ritzmann, R.E. and R.C. Eaton (1997) Neural substrates for initiation of startle responses. In *Neurons, Networks, And Motor Behavior* (Eds. Paul S.G. Stein, Sten Grillner, Allen I. Selverston, and Douglas G. Stuart), MIT Press. (in press).

Schaefer, P.L. , A.J. Pollack, R.E. Ritzmann (1997) Analysis of Descending Influences on Motor Control of Cockroach Escape. *Soc. Neurosci. Abstr.* **23**: in press.

Vaidyanathan, R., Chiel, H.J., and Quinn, R. D. (1997). A hydrostatic robot for marine applications, Proceedings of the 11th VPI&SU Symposium on Structural Dynamics and Control, Virginia Tech, May 12-14, 1997

Watson, J.T. and R.E. Ritzmann (1997) Leg kinematics and muscle activity during treadmill running in the cockroach, *Blaberus discoidalis:* I. Slow running. *J. Comp. Physiol* .(in press).

Watson, J.T. and R.E. Ritzmann (1997) Leg kinematics and muscle activity during treadmill running in the cockroach, *Blaberus discoidalis:* II. Fast running. *J. Comp. Physiol* .(in press).

Watson , J.T. , A.K. Tryba, R.E. Ritzmann, S.N. Zill. (1997) Coordination of Leg Joints During Complex Locomotion in the Cockroach *Soc. Neurosci. Abstr.* **23**: in press.

## Presentations

R. Beer gave an invited talk at the Workshop on Legged Locomotion, MIT, Cambridge, MA, May, 1997.

M. Birch gave a presentation at the Cleveland State University/CWRU student presentation competition, March, 1997.

M. Birch gave a presentation at the ASME Regional Student Conference, Cincinnati, Ohio, April, 1997

H. Chiel gave an invited talk at the Workshop on Legged Locomotion, MIT, Cambridge, MA, May, 1997.

G. Nelson gave a graduate student seminar at CWRU, April, 1997.

R. Quinn gave an invited talk at the Workshop on Legged Locomotion, MIT, Cambridge, MA, May, 1997.

R. Ritzmann gave an invited seminar at Vanderbilt University, Nashville, TN, March, 1997.

R. Ritzmann gave an invited Lecture at the Cleveland Museum of Natural History, Cleveland, OH, April, 1997.

R. Ritzmann gave an invited talk at the Workshop on Legged Locomotion, MIT, Cambridge, MA, May, 1997.

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